

# Identification of blue high proper motion objects in the Tycho-2 and 2MASS catalogues using Virtual Observatory tools

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## ABSTRACT

**Aims.** With available Virtual Observatory tools, we looked for new bright blue high proper motion objects in the entire sky: white dwarfs, hot subdwarfs, runaway OB stars, and early-type stars in nearby young moving groups.

**Methods.** We performed an all-sky cross-match between the optical Tycho-2 and near-infrared 2MASS catalogues with Aladin, and selected objects with proper motions  $\mu > 50 \text{ mas yr}^{-1}$  and colours  $V_T - K_s < -0.5 \text{ mag}$  with TOPCAT. We also collected multi-wavelength photometry, constructed the spectral energy distributions and estimated effective temperatures from fits to atmospheric models with VOSA for the most interesting targets.

**Results.** We assembled a sample of 32 bright blue high proper motion objects, including ten sdO/B subdwarfs, nine DA white dwarfs, five young early-type stars (two of which are runaway stars), two blue horizontal branch stars, one star with poor information, and five objects reported for the first time in this work. These last five objects have magnitudes  $B_T \approx 11.0 - 11.6 \text{ mag}$ , effective temperatures  $T_{\text{eff}} \approx 24,000 - 30,000 \text{ K}$ , and are located in the region of known white dwarfs and hot subdwarfs in a reduced proper motion-colour diagram. We confirmed the hot subdwarf nature of one of the new objects, Albus 5, with public far-ultraviolet spectroscopic data obtained with *FUSE*.

**Key words.** astronomical data bases: miscellaneous – virtual observatory tools – stars: early-type – stars: peculiar – subdwarfs – white dwarfs

## 1. Introduction

Bright objects with blue colours and high proper motions are rare in the sky. By “bright” we mean sources with optical magnitudes in the range covered by classical astronomical catalogues, such as the Bonner Durchmusterung (Schönfeld 1886; Argelander 1903), Córdoba Durchmusterung (Thome 1894), Henry Draper (Cannon & Pickering 1925, and previous versions), or the most recent *Hipparcos* (Perryman et al. 1997) and Tycho-2 (Høg et al. 2000) catalogues. These catalogues typically have higher limit magnitudes between 9 and 11 mag in the visible. Blue colours are indicative of high effective temperatures, while high proper motions of tens of  $\text{mas yr}^{-1}$  imply short heliocentric distances or large tangential velocities at moderate distances.

There are few possible kinds of bright blue high proper motion objects. They can be nearby white dwarfs, hot subdwarfs, runaway OB stars, or early-type stars in nearby young moving groups. Most of the known blue objects (e.g., massive early-type stars in massive clusters) in the Galaxy are located far away and, therefore, have low proper motions and are apparently faint save for a few exceptions. Likewise, a wealth of objects with high proper motions are known, but the bulk of them are neighbouring late-type stars with red colours. Blue extragalactic objects are also known, but they present a negligible proper motion.

Bright blue high proper motion objects are important for many fields in astrophysics. Bright white dwarfs and hot subdwarfs, for instance, are extensively used as spectrophotometric standard stars (Stone 1977; Oke & Gunn 1983; Oke 1990), class

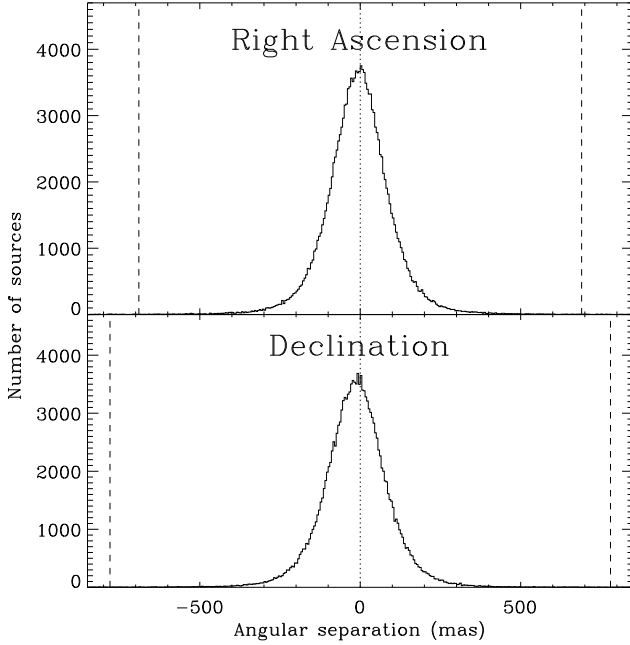
prototypes, or as tracers of the Population II in the Galaxy. Their apparent high optical brightnesses facilitate the determination of physical parameters at extreme conditions (very high temperatures and gravities) in a relatively undemanding way. Similarly, runaway OB stars and early-type stars in young moving groups are fundamental for understanding the evolution and evaporation of star-forming regions.

In this paper, we used Tycho-2 and the Two Micron All Sky Survey Point Source (2MASS; Skrutskie et al. 2006) catalogues and Virtual Observatory tools to look for the bluest objects ( $V_T - K_s \leq -0.5 \text{ mag}$ ) with the highest proper motions ( $\mu > 50 \text{ mas yr}^{-1}$ ).

## 2. Analysis and results

### 2.1. Tycho-2/2MASS cross-match

On the one hand, Tycho-2 gives position and proper motion information for the 2.5 million brightest stars in the sky. Photometric data for two pass-bands ( $B_T$  and  $V_T$ , close to Johnson B and V; Perryman et al. 1997) are also provided. Typical uncertainties are 60 mas in position,  $2.5 \text{ mas yr}^{-1}$  in proper motion, and 0.1 mag in photometry. On the other hand, 2MASS contains photometric data for 471 million sources in the  $J$ ,  $H$ , and  $K_s$  near-infrared bands. Typical photometric and astrometric uncertainties of 2MASS are less than 0.03 mag and 100 mas, respectively.



**Fig. 1.** Histograms of the angular separation in right ascension (upper panel) and declination (lower panel) between the Tycho-2 and the closest 2MASS counterpart, after correcting the 2MASS coordinates for Tycho-2 proper motion. The vertical dashed lines indicate the maximum separation allowed for a reliable cross-match,  $3\sigma_{\rho_\alpha} = 0.69$  arcsec in right ascension, and  $3\sigma_{\rho_\delta} = 0.78$  arcsec in declination.

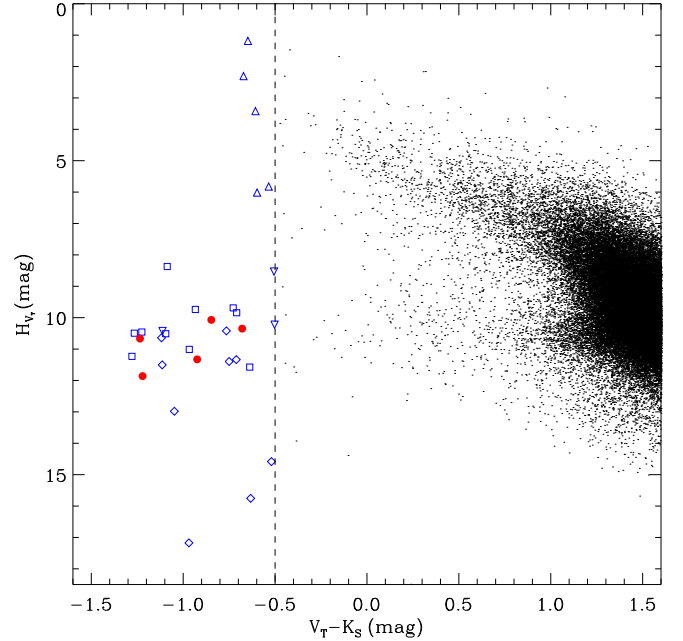
In this work we took advantage of Virtual Observatory<sup>1</sup> (VO) tools to cross-match the whole Tycho-2 and 2MASS catalogues. The VO is a project designed to provide the astronomical community with the data access and the research tools necessary to enable the exploration of the digital, multi-wavelength universe resident in the astronomical data archives. In particular, we made use of the scripting capability of Aladin<sup>2</sup> (Bonnarel et al. 2000) to perform our cross-match, a VO-compliant software that allows users to visualise and analyse digitised astronomical images, and superimpose entries from astronomical catalogues or databases available from the VO services. To avoid memory overflow during data processing, we divided the full sky sphere into overlapping circular regions of  $4.5 \text{ deg}^2$ . The useful and powerful Aladin script mode allowed us to readily perform the following workflow for each region:

- Select all Tycho-2 sources with proper motion  $\mu > 50 \text{ mas yr}^{-1}$ .
- Select all 2MASS sources within a radius of 40 arcsec around each selected high proper motion Tycho-2 source.
- Convert 2MASS coordinates into J2000.0 epoch using the proper motion of the related Tycho-2 source.
- Select for each Tycho-2 source the nearest proper motion-corrected 2MASS source.

In the second step, we used such a large radius to account for the expected high proper motion of the objects along the years. We took as reference the maximum proper motion known so far (that of the Barnard star,  $10.3 \text{ arcsec yr}^{-1}$ ) and the maximum possible temporal separation between Tycho-2 and 2MASS observations ( $\approx 4 \text{ yr}$ ).

<sup>1</sup> <http://www.ivoa.net>

<sup>2</sup> <http://aladin.u-strasbg.fr/>



**Fig. 2.** Reduced proper motion diagram ( $H_{V_T}$  versus  $V_T - K_S$ ). Selected objects are bluewards of the dashed vertical line at  $V_T - K_S = -0.5 \text{ mag}$ . Previously unreported blue high proper motion objects are depicted with (red) filled circles. Already known blue high proper motion objects are shown with (blue) open symbols: hot subdwarfs with squares, white dwarfs with diamonds, young main-sequence stars with up-triangles, and other stars with down-triangles. Objects redder than  $V_T - K_S = -0.5 \text{ mag}$  are marked with (black) small dots.

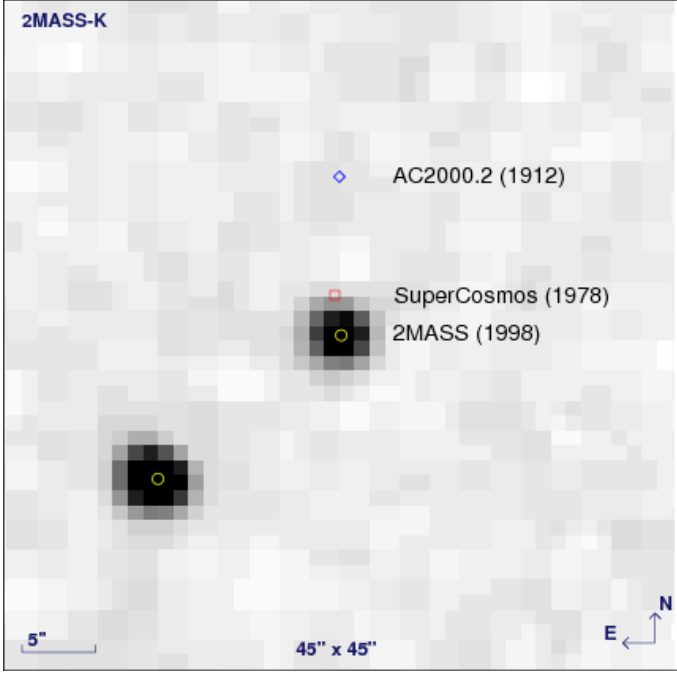
During the cross-match process, we imposed a good quality flag (Qflag = A, B, C, or D) in  $K_s$  and an error lower than 0.3 mag in  $V_T$ . It returned more than 300,000 identifications. However, because we worked with overlapping regions, an important fraction of the identifications were duplicated. We used TOPCAT<sup>3</sup> to purge the duplicated data and to carry out the subsequent analyses. TOPCAT is an interactive graphical viewer and editor for tabular data that allows the user to examine, analyse, combine, and edit astronomical tables. After purging the data we ended with a sample of 157,184 sources fulfilling all the above criteria.

In Fig. 1 we show the histograms of angular separations  $\rho$  between the cross-matched Tycho-2 and 2MASS proper motion-corrected sources, in both directions, right ascension and declination. Most of the separations (98.3%) are lower than 0.50 arcsec. Quantitatively, the mean angular separation and standard deviation are  $\overline{\rho_\alpha} = 0.00 \text{ arcsec}$  and  $\sigma_{\rho_\alpha} = 0.23 \text{ arcsec}$  for the right ascension, and  $\overline{\rho_\delta} = 0.01 \text{ arcsec}$  and  $\sigma_{\rho_\delta} = 0.26 \text{ arcsec}$  for the declination. Thus, we discarded 1,800 (spurious) matches with separations higher than  $3\sigma_\rho$  in any of the spatial directions, which reduced the total number of sources to 155,384.

## 2.2. Colour selection

We show the reduced proper motion-colour diagram of the cross-matched sources in Fig. 2. The reduced proper motion,  $H_{V_T}$ , is defined as  $H_{V_T} = V_T + 5 \log \mu + 5$ , where  $\mu$  is the proper motion in arcseconds per year. It can also be expressed as  $H_{V_T} = M_{V_T} + 5 \log v_t - 3.3$ , where  $M_{V_T}$  is the  $V_T$ -band absolute

<sup>3</sup> <http://www.star.bris.ac.uk/~mbt/topcat/>



**Fig. 3.** Verification of the high proper motion of Albus 4 (TYC 6017–419–1), a representative blue high proper motion object, in a  $K_s$ -band 2MASS image. The epochs of observation in the AC2000.2 (blue diamond), SuperCOSMOS (red square), and 2MASS (yellow circles) are shown in parenthesis. The DENIS epoch almost coincides with the 2MASS one.

magnitude and  $v_t$  is the transverse velocity in kilometers per second. The  $V_T - K_s$  colour is a suitable effective-temperature indicator in field objects. The reduced proper motion diagram therefore constitutes a powerful tool for segregating members of kinematically-distinct stellar populations (e.g. Lépine & Shara 2005). In particular, it is possible to distinguish three types of objects from Fig. 2: Population I (upper branch), Population II stars (middle branch) and white dwarfs (very tiny lower branch).

For selecting blue high proper motion candidates, we applied a very simple selection criterion:  $V_T - K_s < -0.5$  mag, depicted in Fig. 2 with a vertical dashed line. In total, 33 objects showed bluer colour than this value. This simple selection criterion produced an appropriate number of sources that could be studied in detail in a reasonable time scale.

### 2.3. Visual inspection, object rejection, and final sample

We visually inspected the 33 selected blue high proper motion candidates with Aladin. We compared and blinked two sets of images separated several decades in time, optical DSS-1 and near-infrared 2MASS, to easily confirm the high proper motion of our candidates. The Tycho-2 sources and 2MASS counterparts were superimposed on the images to assess the reliability of the cross-match. Besides, we used other available astro-photometric databases, such as the Astrographic Catalogue AC2000.2 (Urban et al. 1998), USNO-B1 (Monet et al. 2003), SuperCOSMOS Sky Survey (Hambly et al. 2001), DENIS (Epchtein et al. 1997) and the Positions and Proper Motions-Extended PPMX (Röser et al. 2008), to verify the high proper motion (Fig. 3).

Of the 33 blue high proper motion candidates, we discarded TYC 8250–687–1, for which Tycho-2 provided an erroneous

proper motion after mixing the star 2MASS 13052225–4740536 ( $V < 10$  mag) with the close ( $\rho \approx 14$  arcmin) bright extended galaxy 2MASX 13052358–4740500 ( $z = 0.01731 \pm 0.00015$ ; Crook et al. 2007).

Of the 32 remaining objects, 27 were already known. We list their basic properties in Table 1. Among them are most of the known brightest white dwarfs and hot subdwarfs. Besides, there are runaway OB stars, early-type stars in young moving groups, and one chemically-peculiar halo blue horizontal branch star. Several of them have their trigonometric parallaxes measured by the *Hipparcos* satellite (van Leeuwen 2007). The trigonometric parallaxes of white dwarfs are larger than those of hot subdwarfs, which indicates longer heliocentric distances and higher luminosities for the latter, consistent with their classification.

The remaining five objects, listed in Table 2, have never before been reported in the literature. For naming them, we followed the “Albus” nomenclature introduced by Caballero & Solano (2007) and followed in Caballero (2009). Our new Albus objects go from the fourth to the eighth of this series.

### 3. Discussion

The five new bright blue high proper motion objects (Table 2) are placed in the reduced proper motion-colour diagram (Fig. 2) in the region at which hot subdwarfs and early-type white dwarfs gather. To shed some light into the nature of the new Albus objects, we searched for additional photometric data with the “all-VO” utility of Aladin. This utility allows the user to query a large number of photometric catalogues in a comfortable way. Besides Tycho-2 and 2MASS, two others catalogues had additional photometric data: DENIS and GRIZ (Ofek 2008). DENIS gives magnitudes in the  $i$  band for the three Albus sources in the Southern hemisphere, whereas the GRIZ catalogue provides synthetic SDSS  $griz$  magnitudes for all new Albus sources but Albus 6 (see Table 2). The typical uncertainty for the GRIZ photometry is about 0.12, 0.12, 0.10, and 0.08 mag ( $1\sigma$ ), for the  $g$ ,  $r$ ,  $i$ , and  $z$ -bands, respectively.

We took advantage of another VO-tool, VOSA<sup>4</sup> (VO Sed Analyzer; Bayo et al. 2008) to fit the observed spectral energy distributions (SEDs) to theoretical models. The VOSA allows the user to query in an automatic and transparent way different collections of theoretical models, to calculate their synthetic photometry, and to perform a statistical test to determine which model best reproduces the observed data. To fit the SEDs of our Albus objects, we used only the observational data (all but the GRIZ ones) and fitted them to Kurucz stellar atmosphere models (Castelli et al. 1997). The effective temperatures  $T_{\text{eff}}$  obtained with VOSA ranged between 24,000 and 30,000 K (see Table 2). The accuracy of the effective temperature estimated with this method is defined by the step of the grid of the model, 1,000 K in this case. In Fig. 4 we have plotted the theoretical fitting of the observational SEDs.

The confirmation of the real nature of these objects requires spectroscopic data. To look for spectra in the VO archives, we used another VO-tool, VOSSED<sup>5</sup>. Developed by the Spanish Virtual Observatory, VOSSED allows the user to gather spectroscopic information available throughout the VO. Only Albus 5 was found to have spectroscopic data. In particular, it was observed by the *Far Ultraviolet Spectroscopic Explorer* (FUSE)

<sup>4</sup> <http://svo.cab.inta-csic.es/theory/vosa>

<sup>5</sup> <http://sdc.cab.inta-csic.es/vosed>

**Table 1.** Already known bright blue high proper motion objects.

| TYC         | $\alpha^a$<br>(J2000) | $\delta^a$<br>(J2000) | $\pi^b$<br>(mas) | Name         | Object type                                      | Ref. <sup>d</sup> |
|-------------|-----------------------|-----------------------|------------------|--------------|--|-------------------|
| 6429–796–1  | 01 43 48.55           | –24 05 10.2           | 3±4              | CD–24 731    | sdO/B hot subdwarf in a close binary system      | 1,2,3             |
| 8055–1270–1 | 02 16 30.58           | –51 30 43.8           | 21.22±0.12       | $\phi$ Eri   | Young B8V star in Tucana-Horologium              | 4                 |
| 9145–601–1  | 03 10 31.02           | –68 36 03.4           | 97.7±1.8         | WD 0310–688  | DA3.1 white dwarf in a wide binary system        | 5,6,7             |
| 83–1181–1   | 04 44 42.13           | +00 34 05.2           | 3.0±0.6          | HD 30112     | Runaway B2.5V star                               | 8                 |
| 3734–2324–1 | 05 05 30.61           | +52 49 51.9           | 18±3             | WD 0501+527  | DA1 white dwarf                                  | 9,10,6            |
| 9166–716–1  | 05 31 40.35           | –69 53 02.2           | ...              | AA Dor       | sdO/B hot subdwarf in an eclipsing binary system | 11,2,12           |
| 7075–2143–1 | 06 04 20.27           | –32 10 20.8           | 3.2±0.3          | 72 Col AB    | Runaway B2.5V star in a binary system            | 13,14,8           |
| 7613–1087–1 | 06 23 12.20           | –37 41 29.0           | ...              | WD 0621–376  | DA1 white dwarf                                  | 15,10,6           |
| 7664–1961–1 | 08 10 31.60           | –40 33 10.0           | ...              | CD–40 3927   | sdO hot subdwarf                                 | 2                 |
| 4547–1009–1 | 09 21 19.18           | +81 43 27.6           | 4±2              | AG+81 266    | sdO hot subdwarf                                 | 16,2              |
| 3429–1180–1 | 09 30 46.78           | +48 16 23.8           | 6.2±1.8          | BD+48 1777   | sdOp hot subdwarf                                | 17,18,2           |
| 3005–579–1  | 10 35 16.71           | +40 21 13.6           | ...              | PB 385       | sdB hot subdwarf                                 | 19,2              |
| 1984–97–1   | 11 37 05.10           | +29 47 58.3           | 63±4             | WD 1134+300  | DA2.5 white dwarf                                | 20,6,7            |
| 2541–4–1    | 13 23 35.26           | +36 07 59.5           | ...              | NSV 19768    | sdOp hot subdwarf                                | 21,22,2           |
| 5545–1390–1 | 13 30 13.64           | –08 34 29.5           | 58±4             | WD 1327–083  | DA3.7 white dwarf in a wide binary system        | 23,6,7            |
| 2004–242–1  | 13 38 24.76           | +29 21 56.0           | 5.5±1.5          | BD+30 2431   | B3Vp halo blue horizontal branch star            | 24,25,26          |
| 7832–2490–1 | 14 58 31.93           | –43 08 02.3           | 8.52±0.18        | $\beta$ Lup  | Young B2III star in Sco OB2                      | 27,28             |
| 7839–874–1  | 15 26 07.13           | –39 29 19.2           | ...              | CD–39 9849   | sdO/B hot subdwarf <sup>c</sup>                  | 29,30             |
| 7853–559–1  | 16 23 33.84           | –39 13 46.2           | 76±3             | WD 1620–391  | DA2 white dwarf in a wide binary system          | 31,6,7            |
| 3885–860–1  | 16 48 25.64           | +59 03 22.7           | 94±3             | DN Dra       | DAV4 white dwarf, pulsating                      | 32,10,6           |
| 8359–3650–1 | 18 26 58.42           | –45 58 06.5           | 11.74±0.17       | $\alpha$ Tel | Young B3IV star in Sco OB2                       | 33,28             |
| 3531–1327–1 | 18 34 08.90           | +48 27 17.0           | ...              | BD+48 2721   | sdB hot subdwarf                                 | 34,2,35           |
| 2161–1038–1 | 20 34 21.88           | +25 03 49.7           | 64±3             | WD 2032+248  | DA2.5 white dwarf                                | 23,6,7            |
| 8424–1008–1 | 21 39 10.61           | –46 05 51.5           | 3.8±1.7          | HD 205805    | sdB hot subdwarf, helium-poor                    | 36,2              |
| 2211–1613–1 | 21 59 41.97           | +26 25 57.4           | 9.1±1.2          | IS Peg       | sdO hot subdwarf in a binary system              | 37,2              |
| 8441–1261–1 | 22 14 11.91           | –49 19 27.3           | ...              | WD 2211–495  | DA1 white dwarf                                  | 15,10,6           |
| 6401–39–1   | 23 12 30.63           | –21 06 43.4           | 0.0±1.4          | HD 218970    | B2–3IV/Vp star found far from the galactic plane | 18,38,39          |

<sup>a</sup> Equatorial coordinates from Tycho-2.<sup>b</sup> Trigonometric parallax from *Hipparcos*.<sup>c</sup> CD–39 9849 was classified as a blue horizontal branch star or sdO/B hot subdwarf by Drilling & Bergeron (1995). We classify it as an sdO/B hot subdwarf based on its location in the reduced proper motion-colour diagram.<sup>d</sup> References. (1) Haro & Luyten 1962; (2) Kilkeny et al. 1988; (3) O’Toole & Heber 2006; (4) Zuckerman et al. 2001; (5) Thackeray 1961; (6) Caballero & Solano 2007; (7) Sion et al. 2009; (8) Hoogerwerf et al. 2001; (9) Greenstein 1969; (10) McCook & Sion 1999; (11) Luyten 1957; (12) Rucinski 2009; (13) Voûte 1918; (14) van Albada 1961; (15) Holberg et al. 1993; (16) Berger & Fringant 1978; (17) Giclas et al. 1967; (18) Greenstein & Sargent 1974; (19) Berger & Fringant 1977; (20) Giclas et al. 1965; (21) Humason & Zwicky 1947; (22) Greenstein 1966; (23) Luyten 1949; (24) Feige 1958; (25) Baschek & Sargent 1976; (26) Bonifacio et al. 1995; (27) Pickering & Cannon 1897; (28) Brown & Verschuere 1997; (29) Drilling & Bergeron 1995; (30) *this work*; (31) Stephenson et al. 1968; (32) Schwartz 1972; (33) Kapteyn 1914; (34) Carnochan & Wilson 1983; (35) Edelmann et al. 2001; (36) Baschek & Norris 1970; (37) Gould et al. 1957; (38) Conlon et al. 1990; (39) Martin 2006.

as part of the programme G061. We used this spectrum to confirm its hot subdwarf nature. In Fig. 5 we compare the *FUSE* spectra of Albus 5 to the well known sdB star HD 205805 ( $T_{\text{eff}} \gtrsim 26\,000$  K; Baschek & Norris 1970). The two spectra are almost identical, showing a huge number of photospheric and interstellar absorption lines that are observed in the *FUSE* spectra of almost all sdB stars (Chayer et al. 2006). Because of the strong similitude of these two ultraviolet spectra and the  $T_{\text{eff}}$  of 24,000 K obtained using VOSA, we classify Albus 5 as a bona-fide sdB star. The other four objects have equal or higher  $T_{\text{eff}}$  (and bluer  $V_T - K_s$  colours) and could be either sdO/B subdwarfs or early-type white dwarfs. Knowing their trigonometric parallaxes would help to classify them. Unfortunately, neither of the five new Albus are included in the *Hipparcos* catalogue.

#### 4. Summary

To find out blue high proper motion objects, we cross-matched the 2.5 million sources in the Tycho-2 catalogue with the 471 million sources in the 2MASS catalogue. From this correlation,

and after discarding one erroneous identification, we obtained a sample of 32 objects with proper motions larger than  $50 \text{ mas yr}^{-1}$  and  $V_T - K_s$  colours bluer than  $-0.5 \text{ mag}$ . Of these, 27 were known and five (Albus 4 to 8) were studied here for the first time.

From the position of the new discovered sources in a reduced proper motion-colour diagram and theoretical fitting of their SEDs, we concluded that these objects are probably hot subdwarfs or early-type white dwarfs. For Albus 5, we confirmed its nature as an sdB star with a *FUSE* far-ultraviolet spectrum. For the remaining objects, spectroscopic follow-up observations are required to ascertain their true nature. In any case, because of their relative brightness and SED profiles, the five objects can serve as useful spectro-photometric standards or be the subject of dedicated studies (e.g., pulsations and origin of hot subdwarfs, metallic abundances and atmospheric parameters in white dwarfs).

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**Table 2.** New bright blue high proper motion objects.

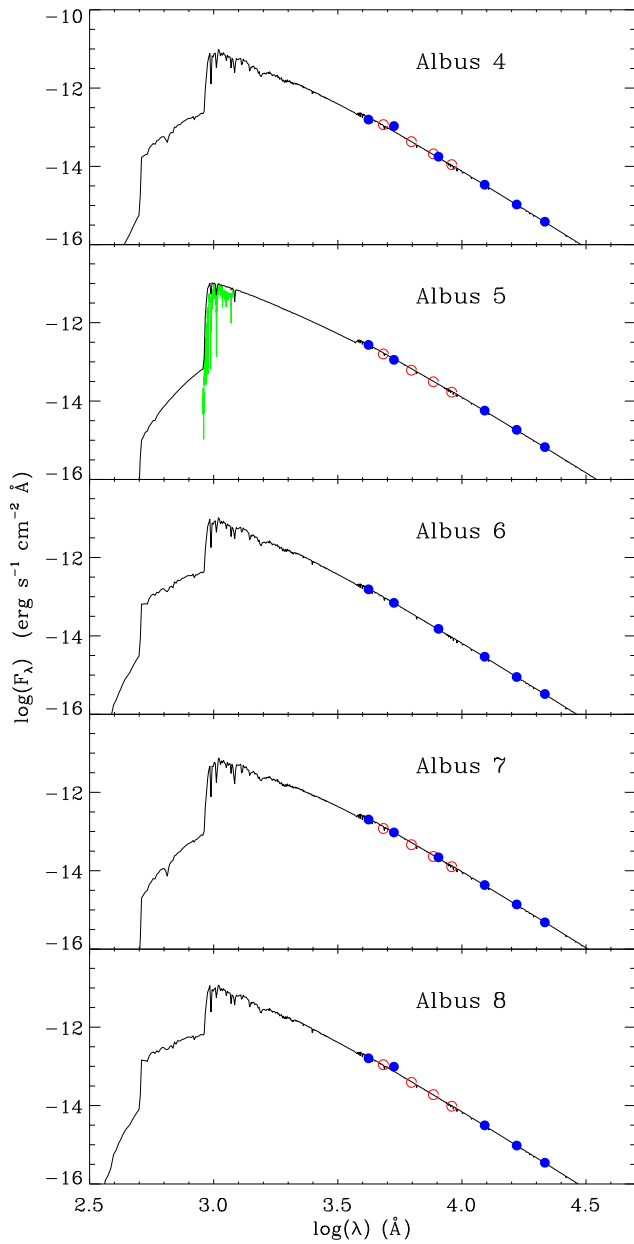
| Albus   | 4           | 5                       | 6           | 7           | 8           |
|---|-------------|-------------------------|-------------|-------------|-------------|
| TYC   | 6017–419–1  | 4406–285–1              | 9044–1653–1 | 9327–1311–1 | 4000–216–1  |
| $\alpha^a$ (J2000)                              | 08 51 58.89 | 14 21 27.86             | 16 00 11.81 | 21 53 41.26 | 23 34 52.08 |
| $\delta^a$ (J2000)                              | –17 12 38.8 | +71 24 21.3             | –64 33 30.3 | –70 04 31.5 | +53 47 02.5 |
| $\mu_\alpha \cos \delta$ [mas a <sup>–1</sup> ] | +0±2        | –62±2                   | +3±3        | +10±2       | +68±2       |
| $\mu_\delta$ [mas a <sup>–1</sup> ]             | –124±2      | –15±2                   | –78±3       | –50±2       | +6±2        |
| $H_{V_T}$ [mag]                                 | 11.86±0.11  | 10.35±0.12              | 11.3±0.2    | 10.07±0.16  | 10.67±0.12  |
| Tycho $B_T$ [mag]                               | 11.56±0.07  | 10.97±0.04              | 11.58±0.07  | 11.28±0.05  | 11.53±0.06  |
| Tycho $V_T$ [mag]                               | 11.40±0.09  | 11.34±0.08              | 11.86±0.15  | 11.53±0.09  | 11.49±0.09  |
| DENIS $i$ [mag]                                 | 12.06±0.03  | ...                     | 12.23±0.04  | 11.83±0.06  | ...         |
| 2MASS $J$ [mag]                                 | 12.41±0.02  | 11.85±0.02              | 12.57±0.03  | 12.15±0.02  | 12.50±0.03  |
| 2MASS $H$ [mag]                                 | 12.55±0.02  | 11.95±0.02 <sup>b</sup> | 12.73±0.04  | 12.26±0.03  | 12.66±0.03  |
| 2MASS $K_s$ [mag]                               | 12.62±0.03  | 12.02±0.03              | 12.77±0.04  | 12.38±0.03  | 12.73±0.02  |
| GRIZ $g$ [mag]                                  | 11.51       | 11.17                   | ...         | 11.48       | 11.57       |
| GRIZ $r$ [mag]                                  | 12.03       | 11.64                   | ...         | 11.95       | 12.13       |
| GRIZ $i$ [mag]                                  | 12.37       | 11.94                   | ...         | 12.26       | 12.47       |
| GRIZ $z$ [mag]                                  | 12.67       | 12.21                   | ...         | 12.52       | 12.82       |
| $T_{\text{eff}}^c$ [K]                          | 27,000      | 24,000                  | 29,000      | 24,000      | 30,000      |

<sup>a</sup> Equatorial coordinates from Tycho-2.<sup>b</sup> Poor  $H$ -band 2MASS photometry quality (flag “E”).<sup>c</sup> Effective temperatures from the SED fits.

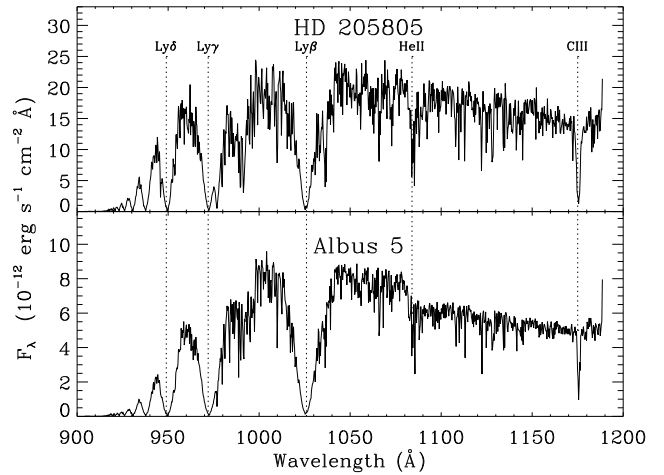
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**Fig. 4.** Theoretical fitting of the Albus SEDs. Solid lines represent the Kurucz models that best fits the observational data. Filled (blue) and open (red) circles indicate the photometric data used for the fit and the synthetic GRIZ photometry data used for control, respectively. The thin (green) line in the second panel depicts the ultraviolet *FUSE* spectra of Albus 5.



**Fig. 5.** *FUSE* spectra of the sdB star HD 205805 (upper panel) and Albus 5 (lower panel). The strongest observed lines (e.g. of the Lyman series) and multiplets (e.g. C III) have been labelled.